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Effects of PRECOOLING on the Market Quality of GLOBE ARTICHOKES

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WARNING

Dehydroacetic acid, tested in this experiment as a possible preventive of decay of globe artichoke buds, must not be so used until a residue tolerance has been established by the Federal Food and Drug Administration for its use on this commodity. Tolerances have been established for postharvest use of this material on bananas, strawberries, and squash, but not on artichokes.

PREFACE

The research reported here was conducted at the request of growers and shippers of artichokes. It is part of a broad program of research by the Agricultural Marketing Service aimed at improving the market quality of agricultural products.

The use of facilities, materials, or services for this study was donated by:

E. Bogiatto and F. Urtaza, Bogiatto Ranch and Packing Co., Inc.; R. Costella, Associated Produce Distributors; V. T. Catalano, Castroville Marketing Association; A. Pieri, California Artichoke and Vegetable Growers Corporation; and D. Dawson, D'Arrigo Bros. Co. of California, all of Castroville, Calif.; and Paul Weaver, St. Regis Paper Co., Salinas, Calif.; and Dow Chemical Co., Midland, Mich. Arthur Greathead, Farm Adviser, Monterey County, made valuable suggestions during the planning of this work.

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Washington, D.C. October 1963

EFFECTS OF PRECOOLING ON THE MARKET QUALITY OF GLOBE ARTICHOKES

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SUMMARY

The market quality of globe artichokes precooled as early as possible on the day of harvest was superior to that of artichokes held 48 hours before cooling when the buds were examined after simulated transit and marketing periods. Precooled lots had less objectionable decay, less wilting and weight loss, and less discoloration than nonprecooled lots. These differences were most apparent after holding periods that included the entire marketing period (8 or 15 days at 37° F. plus 3 days at 59°). Some of the differences in quality were noticeable also after low-temperature holding only.

Room cooling and hydrocooling were about equally effective in retarding deterioration. The addition of a fungicide (dehydroacetic acid) to the hydrocooling water had no effect on the incidence of decay. If thorough hydrocooling (cooling to about 41° F.) is not economically feasible, shorter hydrocooling periods would still be beneficial, if cooling were continued in a cold room or with top ice in a rail car or truck. Free water on the buds, from either hydrocooling or top ice, reduced wilting. The type of container used for packing the artichokes--wooden crates with paper liners or wax-impregnated cartons--had little effect on market quality as long as the buds were properly precooled and top-iced. A perforated polyethylene liner effectively reduced moisture loss from the buds.

Artichokes may be hydrocooled with equal effectiveness either packed or loose on a conveyor belt. The bottom layer in a packed crate, or of buds jumbled about 12 inches deep, required 20 to 30 percent more time for equal cooling than the top layer. Water flow should be 10 to 15 gallons per minute per square foot of cooler area. When lined crates are stacked on top of each other, the top crate must be placed crosswise.

BACKGROUND

Production of globe artichokes (Cynara scolymus) in the United States is concentrated in a few valleys along the Pacific Coast of California, because of their cool, moist climate. While the production is small, compared with that of many vegetables grown in California, its concentration makes the crop of great economic importance to the areas involved. During the 1960-61 season, about 8,500 acres of artichokes, with a market value of over $4.5 million at shipping point[2], were grown in California. Because much of the crop is sold on the East Coast, the industry must minimize loss of quality in artichokes during a handling, transit, and marketing period of 1 to 3 weeks. The industry has become concerned in recent years with losses during this interval.[3] Because 3 days of the interval may represent delay between harvest and cooling, research was requested to evaluate new procedures for precooling and handling before shipment.

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[1] Plant physiologist and horticulturist, respectively, U.S. Horticultural Crops Laboratory, 2021 S. Peach Avenue, Fresno, Calif.

[2] Moore, J. K., and Stoker, W. W. Marketing California Artichokes. Summary of the 1961-1962 Season. Fed.-State Mkt. News Serv., U.S. Dept. Agr. 16 pp. 1962.

[3] Kasmire, R. F., Greathead, A. S., and Snyder, M. J. A Demonstration of the Effect of Careful Handling and Rapid Precooling on the Market Quality of California Globe Artichokes. Univ. Calif. Unnumbered mimeo. 4 pp. Undated (1958?).

Several precooling methods and types of containers were studied to determine their effects on the market quality of artichoke buds after simulated transit and marketing periods. Commercial handling practice was simulated by holding the packed artichokes 48 hours before they were placed in a cold room. The market quality of these buds was compared with that of buds that were room-precooled or hydrocooled on the day of harvest. The effectiveness of a fungicide, dehydroacetic acid (DHA), for control of grey mold was tested in conjunction with hydrocooling.

The rate of heat removal from artichokes during hydrocooling was investigated in relation to the following factors: Size of the buds, arrangement of the buds in the containers, number of layers of buds, method of stacking the crates, rate of water flow, and addition of a wetting agent to the cooling water.

MATERIALS AND METHODS

Studies of Changes in Market Quality

Two market quality tests were conducted, one in March 1960, the other in April 1962, with buds grown near Castroville, Calif. The buds were cut and packed by the ranch crews in the usual manner. The containers employed were the commercially-used wooden crate and wax-impregnated carton (fig. 1). The crates were provided with the usual paper liners or with polyethylene bags to evaluate the importance of moisture retention on quality maintenance. The bags, which were not specially designed for artichoke crates, were perforated with twenty-four 1/4-inch holes per square foot. The initial weight of each container was obtained immediately after packing. The net weights ranged from 8,250 to 10,250 grams (18.1 to 22.5 pounds) per container.

Bud sizes 42 or 48 (number of buds per container) were used in 1960, and size 36 in 1962. These sizes were most readily available and provided an adequate number of buds per sample.

Artichokes to be held 48 hours before cooling remained in a shed for that period; those to be room-precooled were placed in a commercial cold storage room after packing; and those that were hydrocooled were placed in a cold room after completion of each run. The maximum time between harvest and cold storage for the precooled lots was about 7 hours.

Each of the 2 tests consisted of 2 replicates, 4 cooling and 4 container treatments, for a total of 32 lots. The replicates were harvested and treated on successive days, March 29 and 30, 1960, and April 17 and 18, 1962.

Buds were hydrocooled in a small, flood-type cooler[4] for 15 minutes. The water temperature was maintained at 33° to 34° F., and the flow rate was kept at 16 gallons per minute (g.p.m.) per square foot of cooler area. The tops of the paper liners or polyethylene bags were folded back during hydrocooling. The water drained out of the waxed cartons through the usual gap between the bottom flaps.

Dehydroacetic acid (DHA) was used as a fungicide in conjunction with hydrocooling because it had been effective in laboratory tests against botrytis rot, the most common market disease of artichokes. Moreover, it had not injured artichokes at the concentrations effective in reducing decay (according to unpublished data). In the present tests, a concentration of 3,000 parts per million (0.3 percent by volume) was used.

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[4] Stewart, J. K., and Lipton, W. J. Factors Influencing Heat Loss in Cantaloups during Hydrocooling. U. S. Dept. Agr., Mktg. Res. Rpt. No. 421. 12 pp. 1960.

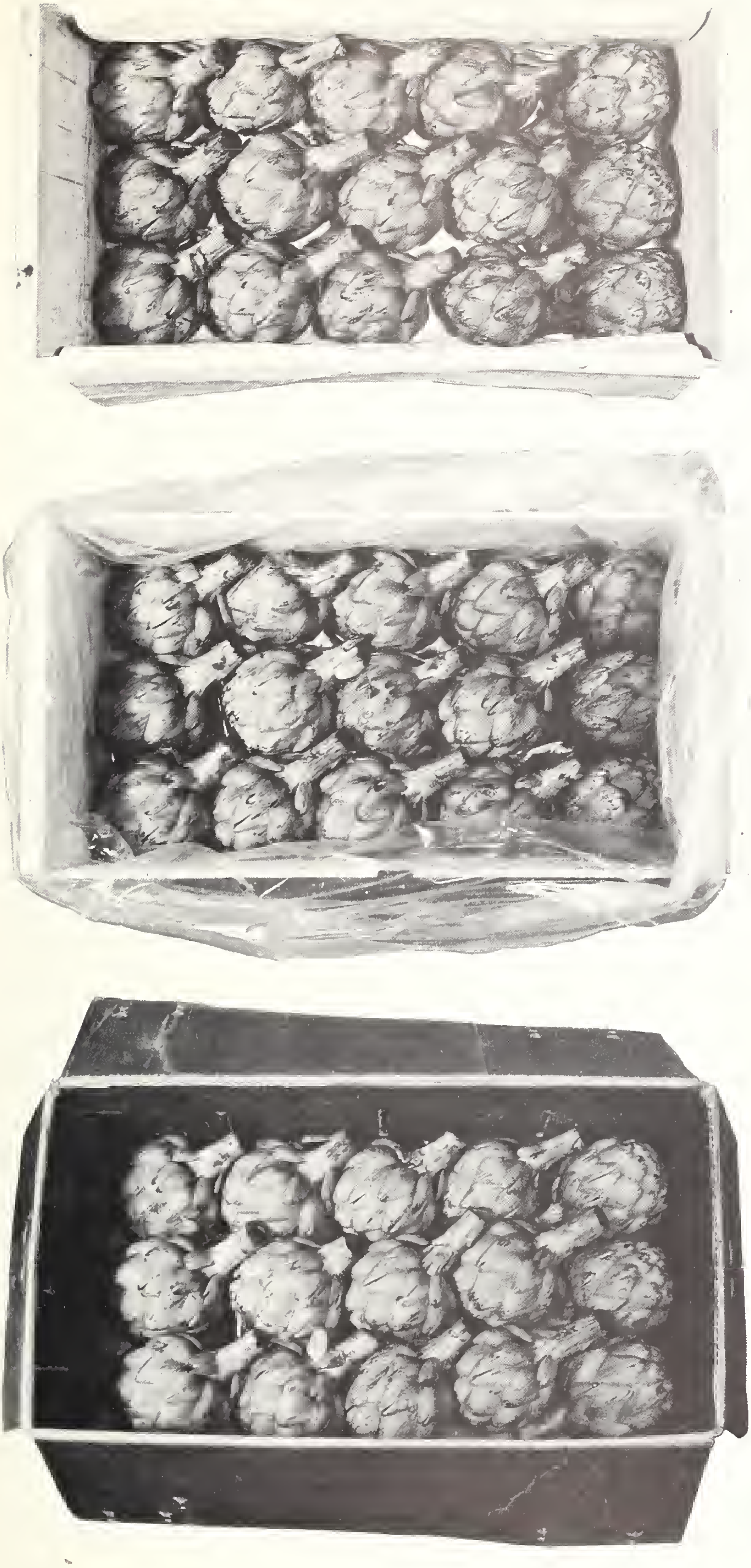

Figure 1.--(Top) Artichokes packed in conventional crate with paper liner; (center) in conventional crate with polyethylene liner; (bottom) in wax-impregnated carton.

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Dehydroacetic acid has not been approved by the Federal Food and Drug Administration for use on artichokes, although it has been approved for postharvest use on strawberries and squash. Use of the acid on artichokes therefore is prohibited until FDA establishes a legal tolerance for residue.

Temperatures of the buds were measured before and after hydrocooling, during room precooling, and during holding in the shed. Thermocouples were inserted 3/4 inch into the base of the buds at a 45-degree angle. Recording thermometers were placed in the center of appropriate containers to measure temperatures during holding. Temperature records obtained during precooling and during holding before cold storage are summarized in table 1. The maximum temperature range of buds harvested on a given day was 8 degrees before and 4 degrees after precooling.

The artichokes were transported to the Fresno laboratory at the end of hydrocooling on the second day of each test. The lots that were to be held 48 hours before cooling were held the remaining time between 55° and 65° F., while all other lots were placed into cold rooms upon arrival at the laboratory.

The artichokes were held in a cold room at 37° F. during the simulated transit-wholesale periods of 8 or 15 days, and at 59° during the simulated retail period of 3 days. The low temperature is within the recommended range of 32° to 41° F.[5] The top-iced crates were covered with a layer of ice throughout the transit-wholesale period. Half the buds in each crate were examined after 8 days and the remainder at the end of 15 days of holding in the cold room. After each of these examinations, the buds were placed in open containers for holding under simulated retail conditions. The relative humidity in the 59° room was 70 to 75 percent. Each sample was weighed at each examination to the nearest 5 grams.

The various quality indexes were judged at each examination and rated as follows:

(1) Decay: 5, none; 4, trace (hardly noticeable, mostly confined to small bracts on pedicel, not objectionable); 3, slight (objectionable, but bud still edible); 2, moderate (lower limit of edibility); 1, severe (inedible).

(2) Brown discoloration: Same rating scale as decay.

(3) Color: 5, deep fresh green; 4, dull green; 3, dull green and slight yellowing near tips of bracts; 2, duller green, increased yellowing of bracts; 1, dull, pale green, yellowing of some entire bracts.

(4) Turgidity: 5, firm; 4, trace of wilting; 3, slightly wilted (may be objectionable to some); 2, moderately wilted (objectionable, but acceptable); 1, severely wilted (unacceptable).

(5) Tightness of buds: 5, tight; 4, few basal bracts pointing away from, rather than toward, tip of bud (frequent condition at harvest, fig. 4a); 3, several whorls of bracts pointing away from, rather than toward, tip of bud (fig. 4b, left bud); 2, all or most outer bracts open; 1, all outer and more centrally located bracts open.

(6) General appearance: 9, excellent (field-fresh, essentially no defects); 7, good (minor, unobjectionable defects); 5, fair (some objectionable defects, can be removed); 3, poor (major defects, unsalable); 1, inedible.

Each bud was examined individually for decay and placed in the proper category; but for all other factors, the judgment was based on the appearance of the entire sample. The ratings given are the result of independent evaluations made by each author.

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[5] Rappaport, L., and Watada, A. E. Effect of Temperature on Artichoke Quality. Conf. Transportation Perishables proc., Davis, Calif. 142-146. 1958.

Table 1.--Time and temperature conditions for precooled and nonprecooled artichoke buds

Date of harvest	Not precooled					Room cooled					Hydrocooled				
	Air temper-ature	Temperature of buds			Time above 41° F.[4]	Air temper-ature	Temperature of buds			Time above 41° F.[4]	Water temper-ature	Temperature of buds			Time above 41° F.[4]
		Ini-tial	End of 48 hrs.[1]	Avg. 48 hrs.[2 3]			Ini-tial	End of 48 hrs.[1]	Avg. 48 hrs.[2]			Ini-tial	At end of cooling	Avg. 48 hrs.[2 5]	
1960	°F.	°F.	°F.	°F.	Hrs.	°F.	°F.	°F.	°F.	Hrs.	°F.	°F.	°F.	°F.	Hrs.
March 29	51-66	65	64	57	89	38-42	64	40	48	53	33-34	59	43	43	53
" 30	--	--	--	--	--	--	--	--	--	--	33-34	56	42	--	--
1962															
April 17	57-70	52	60	54	73	41-50	60	41	50	28	33-34	59	42	47	28
" 18	57-78	58	64	60	89	--	--	--	--	--	33-34	64	45	--	--

[1] This 48-hour period started when the last of the hydrocooled lots was placed into the cold room.
[2] The 48-hour period on which these averages were based started when the last of the hydrocooled lots was placed into the cold room.
[3] The average temperatures were lower than the final temperature because of cooling at night.
[4] Number of hours, starting at time of harvest.
[5] The average temperatures were the same as or higher than the temperatures at the end of cooling because of warming during transit to Fresno.

The appropriate data were tested by analysis of variance and Duncan's multiple range test [6]. Only those differences exceeding the 99-percent level of probability are presented.

Studies of Rate of Heat Removal during Hydrocooling

The factors tested for effect on rate of heat loss during hydrocooling were: Size of buds; arrangement of the buds (either packed in crates or loose to simulate conditions on a conveyor belt); layers of buds; stacking of packed crates two high, either lengthwise or crosswise; rate of water flow; and addition of a wetting agent to the cooling water. The paper liners, used in the commercial packs, were opened and folded back during hydrocooling to avoid interference with water flow. The factors evaluated in a given test are summarized in table 2.

Table 2.--Factors studied in artichoke hydrocooling tests

Test number[1]	Flow rate of water[2]	Bud size	Arrangement[3]		Paper liner	Lid	Crates stacked[4]	Wetting agent[5]
			Packed	Loose				
1	21	36	Tested	Tested	Present	Off	No	Not tested
2	21	72	"	"	"	"	"	"
3	7	36	"	"	"	"	"	"
4	7	72	"	"	"	"	"	"
5	7	36,72	"	Not tested	"	"	"	Tested
6	21	63	"	"	None	"	Yes	Not tested
7	21	36	"	"	"	On	No	"
8	11	36	"	"	"	"	No	"
9	11	63	"	"	"	Off	Yes	"
10	21	63	"	"	Present	"	"	"

[1] Differences between top and bottom layers were measured in all tests.

[2] Gallons of water per minute per square foot of cooler area.

[3] Separate packages were used for each arrangement.

[4] "Yes" indicates 2 crates directly on top of each other, except in test 10 where the top crate was placed crosswise on the lower ones.

[5] Triton W-30 at 600 p.p.m.

Temperatures of the buds were measured during hydrocooling with thermocouples connected to a recording potentiometer. The thermocouples were inserted at a 45-degree angle into the base of the bud above the stem. Temperatures were taken at a depth of 3/4 inch for size 36 buds and 1/2 inch for sizes 72 and 63. This depth placed the sensing points at about the center of the receptacle (fleshy base of the bud). Size 63 was used only when size 72 was not available. The physical dimensions of the several sizes of buds are given in table 3.

The cooling achieved is expressed in terms of half-cooling time, which is the time required to reduce the difference between the initial temperature of the buds and of the water by one-half. The half-cooling time was based in all cases on the initial gradient and the gradient after 15 minutes of cooling. The half-cooling times given are the averages of the half-cooling times of the three replicates.

Statistical treatment of the cooling data was the same as that given for the quality comparisons.

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[6] Duncan, D. B. Multiple Range and Multiple F Tests. Biometrics 11: 1-42. 1955.

Table 3.--Dimensions of artichoke buds of different sizes used in rate-of-cooling studies

Size of buds[1]	Dimension[2]			
	Length		Width	
	Range	Average	Range	Average
	Inches	Inches	Inches	Inches
36	3.2-4.2	3.7	3.1-3.5	3.3
63	2.7-3.1	3.0	2.6-3.1	2.9
72	2.9-3.2	[3] 3.1	2.5-3.0	2.7

[1] Number per commercially-packed container.

[2] Measurements based on 20 buds (length does not include stem).

[3] Variation due to differences in sizing by different packers.

RESULTS AND DISCUSSION

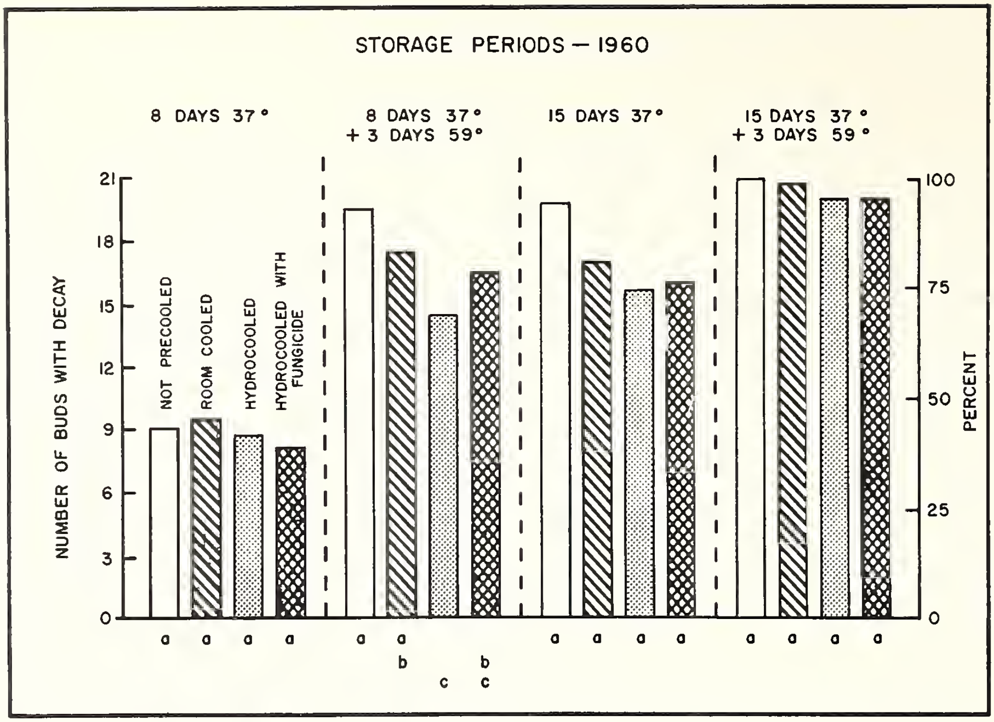
Studies of Changes in Market Quality

Decay.--Decay was evaluated on the basis of (1) the number of buds with any decay and (2) the number of buds with objectionable decay. The first category includes, but is not confined to, buds with even a trace of decay (severity rating 4), an amount which easily could escape detection and probably would not be objectionable. The second category includes only buds with decay that was considered objectionable. Objectionable decay was easily seen and the affected part would have had to be removed before cooking. Such buds were rated 3, or lower, depending upon the severity of decay.

In general, precooled artichokes had fewer buds with decay (category 1) than those not precooled. Method of precooling, however, had no important effect on the incidence of decay (fig. 2). These results were more pronounced and more consistent in 1962 than in 1960.

The effect of precooling on the number of buds with objectionable decay (category 2) is shown in figure 3. Hydrocooling or room-precooling resulted in significantly less objectionable decay than was found in buds that were not precooled, at all examinations in 1962 except the shortest one (8 days at 37° F.). In 1960, however, the advantage of precooling was significant only after 15 days at 37° plus 3 days at 59°. Objectionable decay occurred about equally in artichokes that were room-precooled, and those hydrocooled with DHA or without DHA. Some differences in appearance between nonprecooled and precooled buds are shown in figure 4.

Although the benefits of precooling may not be apparent at the end of a normal transit period at desirable temperatures (8 days at 37° F.), the benefits would become evident at the retail store or in the home, where the artichokes are sold and consumed. A substantial number of incipient infections existed in all lots of artichokes used, even though no lesions, or only a few, were visible at harvest or at the first examination. These incipient infections must have become far better established in the nonprecooled artichokes than in those precooled, for once the artichokes were removed from the low temperature,



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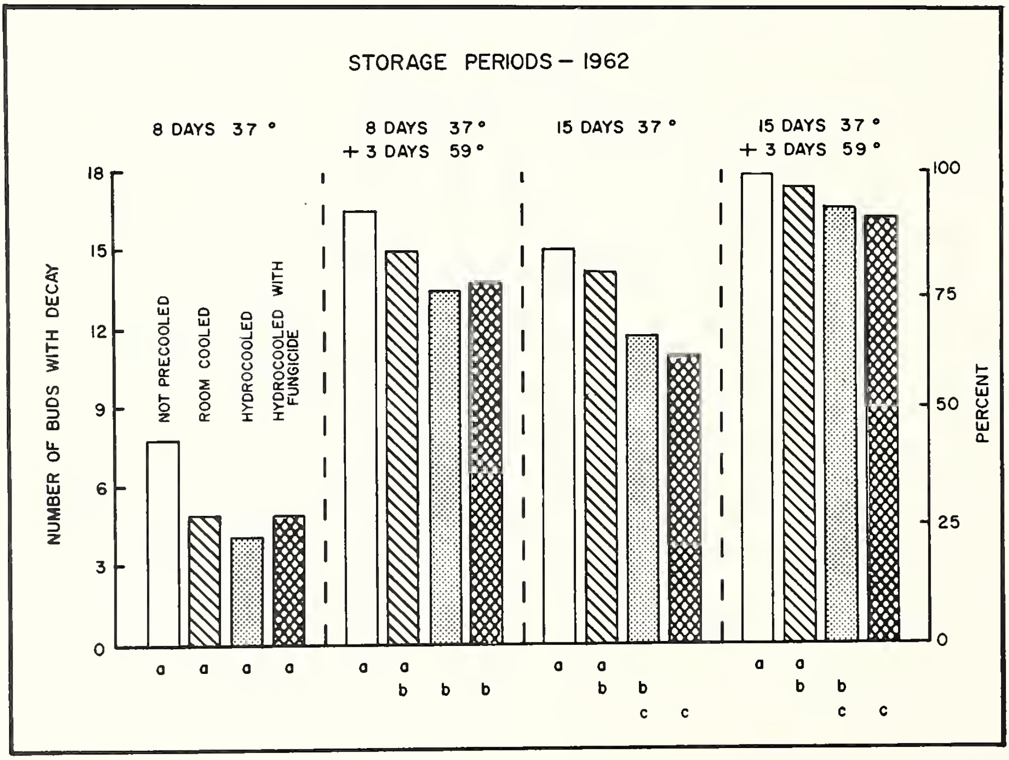

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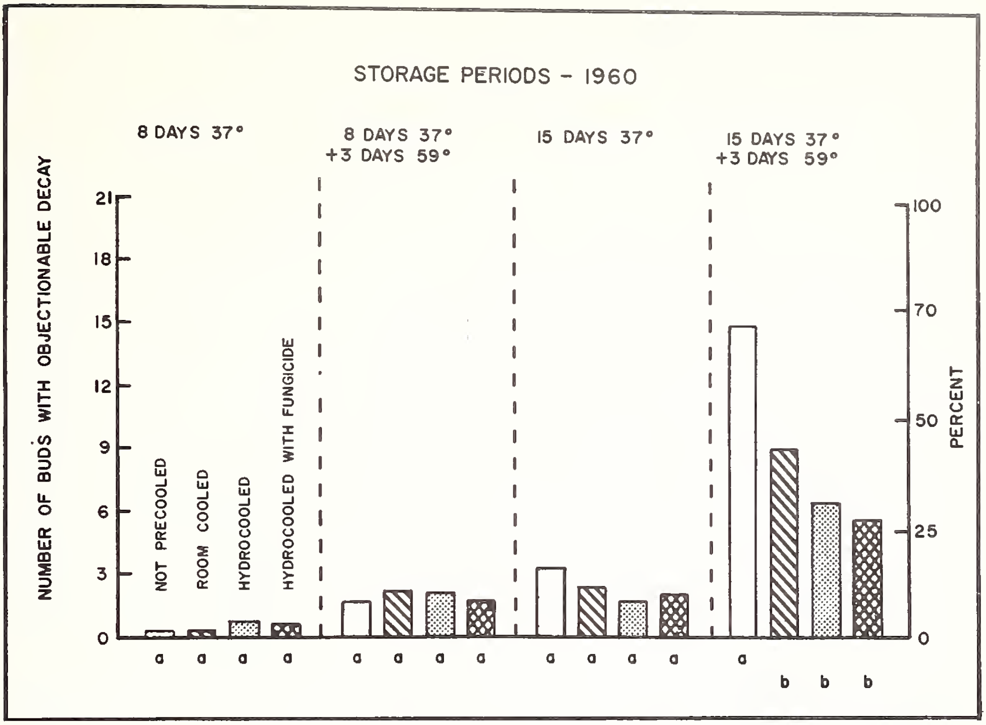
Figure 2. --Effect of precooling on the number of artichoke buds with decay after various holding periods. Treatments at a given examination differ at the 99 percent probability level only if they have no letter in common.



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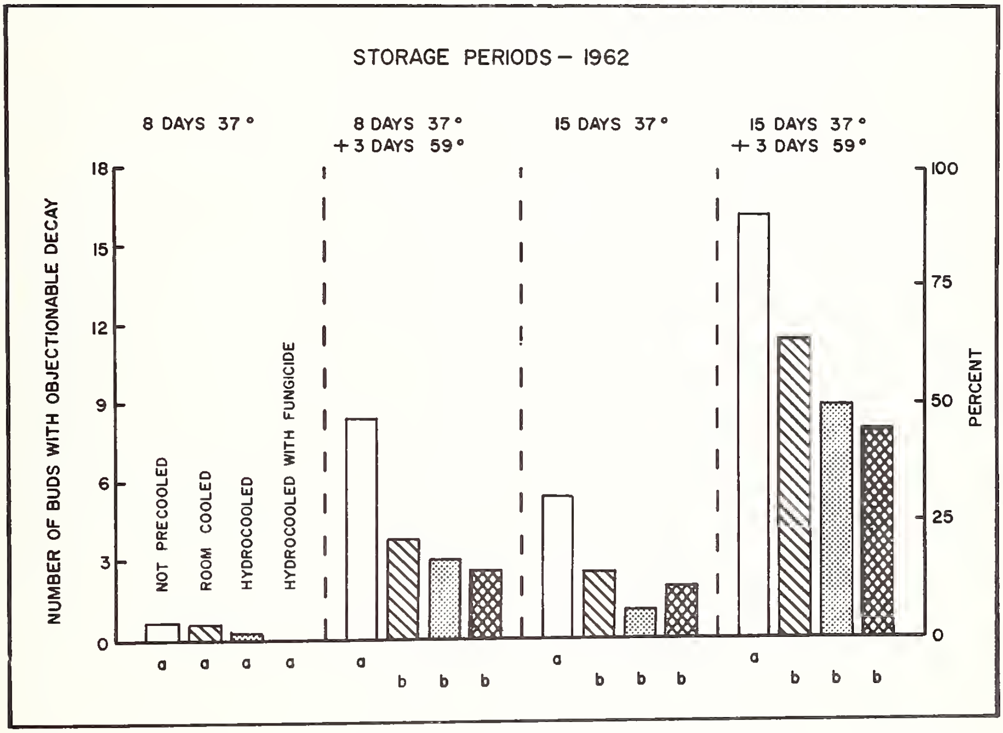

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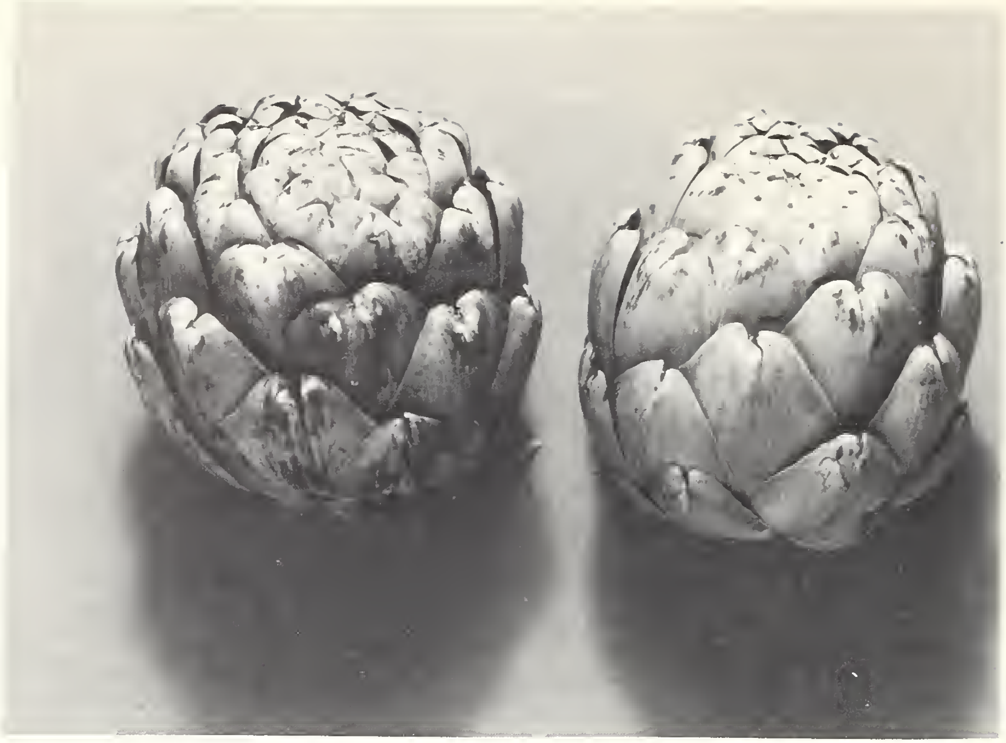
Figure 3. --Effect of precooling on the number of artichoke buds with objectionable decay after various holding periods. Treatments at a given examination differ at the 99 percent probability level only if they have no letter in common.



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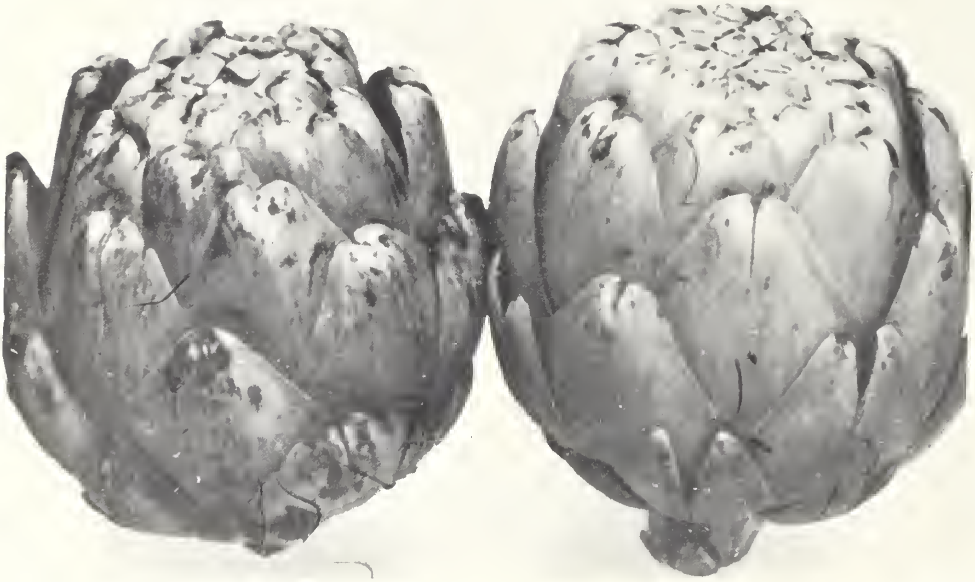

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Figure 4. --(Top picture) Appearance of artichoke buds after 8 days at 37° F., illustrating maximum difference between precooling treatments. Left, representative of poorest in nonprecooled lots; right, representative of best in precooled lots. Large dark areas on left bud were decayed, smaller ones on both buds due to scuffing. (Bottom picture) Typical buds from precooled (right) and nonprecooled (left) lots after 15 days at 37° F. Note greater amount of discoloration in nonprecooled bud.

decay developed much more rapidly in the nonprecooled artichokes than in those precooled. This finding confirms earlier laboratory observations[7] that showed the effect of temperature on rate of decay development to be greatest during the early stages of incubation. This retardation in the spread of decay is attributed to the relatively slow growth of the organism at the low temperatures prevailing after precooling.

The container in which the artichokes were packed had no significant effect on the incidence of decay. This result emphasizes the value of precooling to reduce decay, regardless of the container used for shipping the buds. High humidity, which occurred in the polyethylene-lined crates, and even free water did not increase decay when buds were held at desirably low temperatures.

Wilting.--Wilting, or loss of turgidity, was the most serious and most readily noticeable form of deterioration, except for decay. The high incidence of this defect was noted also by Rappaport and Watada[8].

Precooling, either in a cold room or with water, helped prevent wilting (table 4). In 1960, the advantage was found in the examinations made after the simulated retail period; in 1962, it was evident in all but the first examination. This variation in response is attributed to the initial wetness of the buds; those used in 1960 were harvested during a drizzle, while those used in 1962 were cut during clear, dry weather. Thus, atmospheric moisture substituted for rapid cooling in relation to wilting.

Table 4.--Effects of method of precooling on wilting of artichoke buds after various holding periods

Holding period		Not precooled	Room precooled	Hydrocooled
Days at 37° F.	Days at 59° F.			
1960		Rating[1]	Rating	Rating
8	-	4.6 a	4.6 a	4.7 a
8	plus 3	2.5 a	3.1 b	3.6 b
15	-	4.1 a	4.4 a	4.5 a
15	plus 3	2.1 a	2.9 b	3.1 b
1962				
8	-	[2] 3.9 a	4.1 a	4.4 a
8	plus 3	2.4 a	3.1 b	3.3 b
15	-	3.7 a	4.2 b	4.6 b
15	plus 3	2.3 a	2.9 b	3.1 b

[1] 5, firm; 4, trace of wilting; 3, slightly wilted; 2, moderately wilted; 1 severely wilted.

[2] Ratings for any one holding period of a given year differ at the 99 percent probability level only if they have no letter in common. The letters do not apply to comparisons among holding periods.

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[7] Lipton, W. J., and Harvey, J. M. Decay of Artichoke Bracts Inoculated with Spores of *Botrytis cinerea* Fr. at Various Constant Temperatures. U. S. Dept.. Agr., Plant Disease Reptr. 44: 837-839. 1960.

[8] See footnote 5, p. 6.

Wilting was influenced also by the container in which the buds were packed. The buds from the crates held under top ice were consistently the most turgid, those held in the crates without top ice or in the wax-impregnated cartons were least turgid, and those held in crates lined with perforated polyethylene were intermediate in turgidity. The polyethylene liner effectively retarded wilting while the buds were packed in the lined crate, but had no carry-over after the buds were removed. The benefit of the top ice, however, carried over to the period when the buds were held in the open containers at 59° F. This was most likely an effect of the free moisture from the melted ice, adhering to the buds. The benefit of top ice was particularly evident in the nonprecooled lots. While buds from the two containers that were neither precooled nor top-iced were almost inedible after 15 days at 37° F. plus 3 days at 59° (wilting rating, 1.3 and 1.5), those from the top-iced crates were still acceptable (wilting rating, 3).

Weight changes.--The method of precooling as well as the type of container greatly affected weight changes in artichokes during the various holding periods in 1962. The weight change data for 1960 were inadequate for evaluation. Room-cooled buds lost significantly less weight than nonprecooled buds, and those hydrocooled lost significantly less than those given either of the other treatments during all holding periods considered. The hydrocooled lots weighed more after 8 or 15 days at 37° F. than initially, because of retention of free moisture on the buds (fig. 5). This moisture also contributed to the low

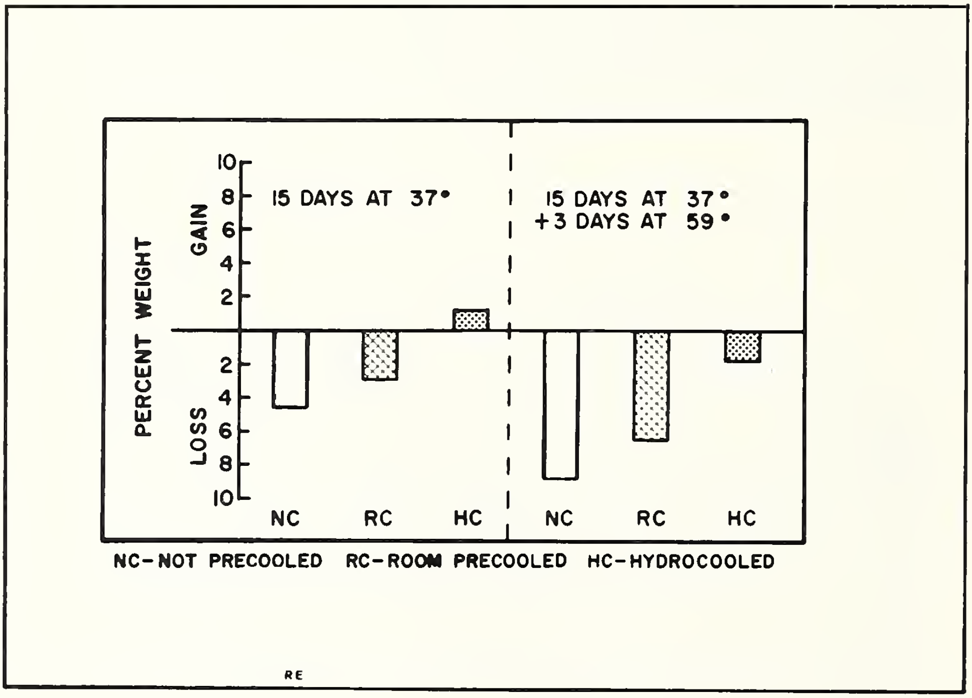

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Figure 5.--Effects of precooling on weight changes of artichoke buds during several holding periods. Treatments for a given holding period differ from each other at the 99 percent probability level.

percentage of weight loss in the hydrocooled lots during subsequent holding at 59°. The difference in weight loss between the room-cooled buds and those not precooled is apparently due to different holding conditions during the initial 48 to 89 hours (see table 1), because the subsequent external environment was the same for both groups.

The total weight losses included the direct loss of water and also the respiratory loss of carbon dioxide. The proportion of weight loss attributable to water loss differed little between lots that were not precooled and those that were room cooled, but the proportion attributable to water loss was greater after holding at 59° F. than at the lower temperature (table 5). The percent of water loss given for the hydrocooled buds may be lower than warranted, because any small water loss from tissue would be masked by the presence of an unknown amount of free water on the surface. These data make it clear, however, that water loss from tissue may be greatly reduced in the presence of free water on the buds.

Table 5.--Percentage of total weight loss of artichoke buds attributable to water loss during holding, 1962[1]

Holding period		Not precooled	Room precooled	Hydrocooled
Days at 37° F.	Days at 59° F.			
		Percent	Percent	Percent
8	-	69	63	[2] -
8	plus 3	83	81	50
15	-	67	57	[2] -
15	plus 3	77	72	0

[1] Based on the respiration data of Rappaport and Watada. See footnote 5, p. 6.

[2] Free moisture remaining from hydrocooling resulted in weight gain.

The expected reflection of weight loss in turgidity ratings was realized with respect to differences between nonprecooled lots and those precooled, except after 8 days at 37° F. Differences in weight loss between the two precooled groups were detected only by weighing, not by the less objective turgidity ratings.

The differences in the amount of weight lost by artichokes in the various containers depended entirely on their effectiveness as a moisture barrier or on a supply of free water, because the temperatures were essentially the same for all containers within a given precooling treatment. This dependence is well illustrated by the data in table 6. At most examinations, the lots held under top ice or those held in crates lined with perforated polyethylene lost significantly less weight than those held in either the crate without top ice or in the wax-impregnated carton. The waxed carton afforded significantly better protection from moisture loss than the crate when neither container was top-iced.

Precooling method had no significant effect on the weight loss of buds in polyethylene liners during holding 15 days at 37° F. or 15 days at 37° plus 3 days at 59°. After 15 days, the losses ranged from 1.9 to 2.1 percent, and after the additional 3 days, they ranged from 3.1 to 5.5 percent. Use of a polyethylene liner or bag is, therefore, advisable where artichokes are not covered with top ice while held under refrigeration. This procedure is currently used with artichokes sold at some roadside stands, and might be adaptable to shipments for nearby markets.

Brown Discoloration.--Brown discoloration of artichoke buds, other than that caused by decay, usually follows freezing injury or mechanical damage. It detracts from the appearance of the buds as it becomes aggravated during marketing[9].

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[9] See footnote 3, p. 3.

Table 6.--Effects of container and top ice on weight loss by artichoke buds during holding

Holding period		Container			
Days at 37° F.	Days at 59° F.	Crate	Crate with polyethylene liner	Crate with top ice	Waxed carton
		Percent	Percent	Percent	Percent
8	[1]-	[2] 4.6 c	1.5 a	2.4 ab	3.2 b
8	plus 3	7.6 a	5.6 a	5.7	6.8 a
15	[1]-	6.5 c	2.1 a	2.1 a	4.6 b
15	plus 3	8.1 c	4.7 a	3.3 a	6.6 b

[1] Hydrocooled lots not included after 8 or 15 days at 37° F. because of free moisture remaining at these examinations. Nonprecooled and room-precooled lots included in all examinations.

[2] Percentages for any one holding period differ at the 99 percent probability level only if they have no letter in common. The letters do not apply to comparisons among holding periods.

The precooled lots discolored significantly less during the longer holding periods than those not precooled (table 7). The difference between the precooled and nonprecooled lots suggests that the discoloration began during the 48-hour interval between harvest and cooling, but that it became visible only when holding conditions permitted its expres-

Table 7.--Effects of method of precooling on brown discoloration of artichoke buds during holding

Holding period		Not precooled	Room precooled	Hydrocooled	
Days at 37° F.	Days at 59° F.			Without fungicide	With DHA[1]
1960		Rating[2]	Rating	Rating	Rating
8	-	[3] 3.9 a	4.0 a	4.1 a	4.1 a
8	plus 3	3.3 a	3.6 a	3.6 a	3.7 a
15	-	3.4 a	3.9 b	4.0 b	3.9 b
15	plus 3	2.4 a	2.9 b	3.2 b	3.1 b
1962					
8	-	[3] 3.7 a	3.7 a	3.8 a	3.7 a
8	plus 3	2.3 a	2.8 ab	3.0 b	2.9 b
15	-	3.2 a	3.9 b	3.8 b	3.7 ab
15	plus 3	2.1 a	2.8 b	3.1 b	2.7 b

[1] Dehydroacetic acid, 3,000 p.p.m.

[2] 5, none; 4, trace; 3, slight; 2, moderate; 1, severe.

[3] Ratings for any one holding period of a given year differ at the 99 percent probability level only if they have no letters in common. The letters do not apply to comparisons among holding periods.

sion. The fungicide DHA in the hydrocooling water had no influence on the brown discoloration. Precooling not only resulted in less browning at a given examination, but also slowed its increase from the first to the last examination. In the lots held 48 hours without cooling, the average quality rating decreased 1.5 and 1.6 points on the scale during the 10-day interval between the first and last examinations, while in the precooled lots the decrease ranged from 0.7 to 1.1 points.

The effect of container on discoloration was negligible, indicating that this defect is more influenced by temperature than by relative humidity. The influence of different containers and liners on the amount of mechanical injury that may occur during normal marketing was not tested.

Fading of green color.--Fading of the deep green of fresh artichokes was not as greatly influenced by precooling treatment as was the brown discoloration. The color of nonprecooled lots had faded to a greater extent than that of those precooled, after all but the shortest holding period in 1960, but the difference was of practical importance only after 15 days at 37° F. plus 3 days at 59° . In 1962, the influence of precooling on green color change was even less than in 1960. This relative insensitivity of the green color of artichokes to temperature has also been observed by Rappaport and Watada[10]. Type of container had no influence on the loss of green color.

Tightness of buds.--Neither precooling treatment nor type of package had any effect on the tightness of buds during holding. The buds, however, did open up somewhat during holding, changing from initial ratings ranging from 4.5 to 5.0 to a final rating of 3.5.

Factors Influencing Rate of Heat Removal during Hydrocooling

Size of buds.--As expected, the large buds (36's) cooled significantly slower than the small ones (72's). The respective half-cooling times were 17 and 9 minutes. Therefore, the large buds must remain in the hydrocooler almost twice as long as the small ones to reduce the initial gradient between the buds and the water by one-half. If, for example, the buds were initially 70° F. and the water 32°, a difference of 38°, the small buds would be at 51° (70° - 19°) after only 9 minutes, while the large ones would require 17 minutes to reach the same temperature.

Effect of layer.--The top layer of buds consistently cooled more rapidly than the bottom layer, regardless of size of buds. This result was found in packed crates as well as when the buds were jumbled about 12 inches high to resemble the arrangement on a conveyor belt. Generally, the lower layer in the packed or jumbled arrangement required 20 to 30 percent more time than the top layer for equal cooling. In no case did the container fill up with water during cooling.

Arrangement of crates.--Economic considerations often limit the time available for hydrocooling. Therefore, a maximum volume of produce must be cooled per unit of time. If stacking packed containers two high were possible, the volume that could be handled would be about doubled. With the presently used paper liner (crate open, liner folded back), stacking crates directly on top of each other is impossible because the paper prevents the water from reaching the lower crate. Consequently, two alternative stacking patterns were tested: First, open, unlined crates were placed directly on top of each other; and second, open, lined crates were placed to straddle two lower crates. In the latter case, part of the bottom crate was exposed to the shower directly, part was cooled by water flowing out of the top crate, and part was not cooled by water at all--only by conduction or convection after hydrocooling.

With either arrangement the top crate cooled more rapidly than the lower one, but there was no significant difference between lower crates in the two arrangements. The half-cooling times were about 7 minutes for the upper crates and about 10 minutes for the lower ones.

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[10] See footnote 5, p. 6.

Other Factors.--Rate of water flow (7, 11, or 21 g.p.m.) had no effect on the cooling rate of the buds, regardless of any other variable tested.

Addition of a wetting agent to the cooling water did not affect the cooling rate of either large or small buds packed in crates.

Lidding of unlined crates did not increase the half-cooling time above that of open, lined crates.

CONCLUSIONS AND RECOMMENDATIONS

A comparison of the market quality of precooled and nonprecooled artichoke buds after simulated marketing periods and conditions strongly suggests that this commodity should be precooled promptly after harvest. Delays between harvest and precooling that exceed 1 day should be eliminated. A 48-hour delay reduced quality substantially; longer delays, which do occur in the industry, would be correspondingly more harmful. Whether the artichokes are to be room-cooled or hydrocooled can be decided primarily on the basis of economic considerations, because the type of precooling had little effect on quality.

Even where room precooling is used, washing the buds in cold water appears beneficial, because the free water on the buds reduces moisture loss during marketing. If a wash were used and the water were recirculated, the addition of chlorine as an antimicrobial, would be advisable to check the multiplication of bacteria in the water. The use of a fungicide, such as DHA, in the cooling water cannot be recommended because it did not reduce decay.

Hydrocooling of artichokes would likely be economically feasible if a large enough volume were handled or if the same equipment were used for other crops that benefit from quick cooling, such as broccoli, cauliflower, carrots, Brussels sprouts, or radishes.

The type of container used for artichokes--crate or wax-impregnated carton--was of minor importance as long as the buds were adequately precooled and top iced. Perforated polyethylene liners were very effective in reducing moisture loss, and would be compatible with either room precooling or hydrocooling. They must, however, be adequately ventilated to allow for heat exchange, to avoid buildup of carbon dioxide and depletion of oxygen, and to provide for adequate drainage in hydrocooling. The liners used in these tests, provided with twenty-four 1/4-inch holes per square foot, were satisfactory even though not designed for artichoke crates. Liners with twice that number of holes per unit of area would still effectively retard moisture loss, and would provide improved heat exchange and water drainage.

For hydrocooling artichokes, a water flow of 10 to 15 g.p.m. was adequate. Lower flow rates may not provide proper distribution of water in commercial coolers, while higher rates do not improve cooling performance. The water for cooling should be as near 32° F. as possible at all times, because the amount of cooling per unit of time is directly related to the temperature gradient between commodity and water. With the limited time usually available for hydrocooling, the importance of keeping the water well iced cannot be overstated.

The buds may be hydrocooled before or after packing, because the rate of cooling was the same for loose or packed artichokes. If they are cooled before packing, there may be some waste of refrigeration, since the buds will warm up while waiting to be packed and placed in a cool room or in a refrigerated rail car or truck. If initial bud temperatures were near 70° and the water temperature below 35°, 5 to 8 minutes in the hydrocooler would be adequate for the small sizes (60 or smaller), 10 to 12 minutes for the medium sizes (54's to 30's), and 15 to 18 minutes for the largest ones. These cooling times are weighted for the proportion of fast and slow cooling tissue as determined experimentally in subsequent tests.[11] These hydrocooling periods, or slightly shorter ones, are adequate when cooling is continued in a cold room or under top ice in a rail car or truck.

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[11] It is intended that results of these tests will be published as part of a comprehensive study on hydrocooling of various vegetable crops.